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Development and testing of a new alpha radiac

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A new, state-of-the-art alpha radiac has been developed to monitor for alpha contamination in both laboratory and field operations. The detector is a 7.6 cm (3 inch) diameter circular diffused-junction semiconductor with an active detection area of 42.6 cm^2. Its surface is coated with aluminum and a thin layer of epoxy to provide light shielding and protection against abrasion during decontamination. The modular design of the detector-preamplifier, the probe processor unit and the detector interface unit allows for ease in replacement. The electronic components are contained in the probe housing so that only the processed, digitized detector signal is sent to a separate, detached display device. An external computer and IEEE connector are used to set the detector threshold levels and operational parameters, e.g. various calibration factors. Additional enhancements include shock hardening of the detector assembly, shielding from electromagnetic interference, and a removable decontamination shield. Testing and evaluation of prototype units were performed at several military and civilian laboratories to determine the detector's limitations and abilities to monitor alpha radiation, and to determine its capabilities under various operational conditions. These tests indicate that the radiac meets or exceeds the requirements.

1. Introduction

The U.S. military services require portable detection equipment to monitor for alpha contamination in maintenance areas and in field operations that involve the cleanup of Pu-contaminated or nuclear-accident sites. Of specific concern is the ability to survey for the unrestricted release of property and equipment within established or proposed guidelines [1–3]. Currently available radiacs, which use ZnS scintillators with photomultiplier tubes, have several performance limitations that are summarized in table 1. In addition, the units lack reliable accuracy when used for surveying, even in the hands of routine users [4].

A development and procurement program was initiated to obtain a new radiac that would overcome the operational shortcomings of the current devices and meet the new requirements for the unrestricted release of property. The new device would have to (1) measure alpha contamination down to a level of 200 dpm/100 cm^2, (2) be human-factor engineered, (3) be easily decontaminated, and (4) be able to detect a 200 dpm point source with 63% confidence at a distance of 0.5 cm while scanning at 10 cm/s.

The decision to use a solid-state detector system was based on several factors. Solid-state silicon diode detectors have been used for many years in health physics applications. They are shock-resistant, and require low voltages and minimal electronic circuitry. Current manufacturing techniques permit the production of large-surface-area silicon wafers that can be several centimeters across.

Throughout the development phase and initial testing of prototype units, input was solicited from repre-

Table 1
Comparison of ZnS/PM tube and solid-state detector performance factors

	ZnS/Pm tube detector [a]	Silicon wafer detector
Sensitivity (2π)	< 40%	~ 94%
Shock/drop resistance	Limited	Good, with hardened housing
Ruggedness	Poor to fair, Mylar window easily damaged; light leakage damaging PM tube	Good, with hardened coating to resist surface abrasion; maintain light tightness
Power-supply requirements	≥ 1000 V	24 V
Warm-up time	~ 15 min	None
Time needed for calibration	hours	< 0.5 h

[a] Based on present ZnS/PM tube technology used by the military services (AN/PDR-56)

sentatives of the military services to ensure that the final product met their requirements. In addition, a complete battery of tests evaluated the radiac's radiation detection capabilities, and survivability in harsh environments and rough handling.

2. Detector, electronics and enhanced signal development

The detector used in the new radiac is a 46 cm (3 inch) diameter, 0.508 mm (0.02 in.) thick "p-type" double-diffused-junction silicon wafer diode. Tests show that the detector efficiency is 94.1% for a 2π point source. The detection surface is coated with a 2500 Å (0.25 μm) thick layer of epoxy that is spun onto the surface, and an aluminum coating that is also 2500 Å (0.25 μm) thick. This coating causes a decrease of approximately 400 keV in alpha-particle energy. The detector itself is attached to a shock-absorbing foam backing using a fiber glass/epoxy matrix, and is mounted in a Kovar/Ni ring to provide uniform thermal expansion.

The detector is connected to a low-noise 1 GHz gain-bandwidth amplifier circuit that forms a singular detector subassembly (DET). The DET is connected directly to the detector interface unit (DIU) and probe processor unit (PPU) by a detachable connector. This arrangement allows for easy disassembly of the unit and replacement of component parts within 15 min.

A preamplifier circuit in the DET consisting of a wide-band field-effect transformer (FET) that converts detector charge pulses into voltage pulses. The voltage pulses are shaped by four wide-band operational amplifiers with a nominal time constant of 1.25 μs. The preamplifier also incorporates a test-pulse circuit that routes pulses generated by the microprocessor in the PPU through the system to provide for internal self-testing. A Delrin ring placed between the DET and DIU/PPU assemblies holds the shock ring in place and separates the subassemblies.

The DIU provides voltages to the DET and PPU with three voltage converter systems which allows the external battery voltage to vary without effecting the probe performance. In addition, a dual discriminator in the DIU compares the incoming analog signals from the DET, with two threshold levels provided by the microprocessor in the PPU. The output pulses are stretched into logic level signals that are counted by the microprocessor.

The PPU uses an 80C51FA-based signal microcontroller to monitor the response of the DET and communicate with external devices through a modified serial bus. The microcontroller contains 8 kbytes of electrically erasable read-only memory (EEPROM), 256 kbytes of random-access memory (RAM), pulse-width modulating analog-to-digital converters, and the 8-bit microprocessor. The EEPROM is used to store calibration factors and threshold discrimination levels. No potentiometers are used in the probe which prevents variations of performance over time due to changes in potentiometer values. The microcontroller generates digital signals that are sent to the external meter. The total power consumption of the probe electronics is approximately 183 mW.

The detector and electronic system are designed to provide the following features to a newly designed, stand-alone display unit:

(1) three sampling modes (peak, average, scalar);
(2) dual, variable discrimination thresholds;
(3) selectable sampling times;
(4) multiple tone outputs for headphones:
 (a) clicks proportional to the counting events;
 (b) 1 kHz tone for threshold alarm;
(5) selectable alarm thresholds for each sampling mode;
(6) selectable time interval for back-light illumination;
(7) programmable conversion factor (counts to disintegration);
(8) battery life indicator;

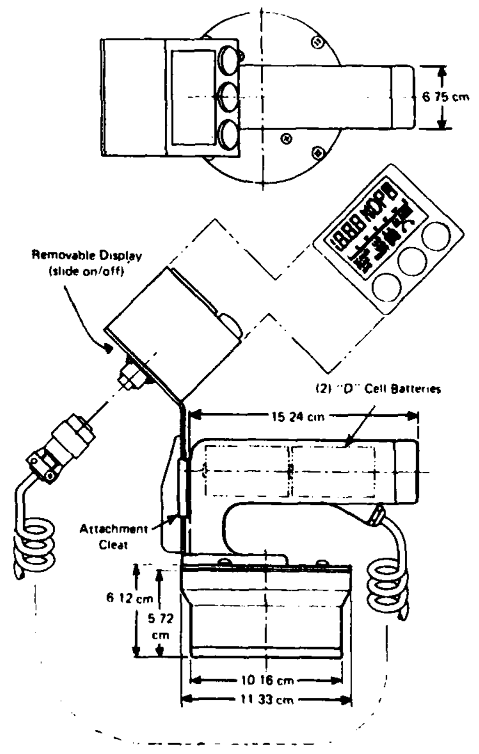

Fig. 1. Alpha radiac with removable stand-alone display unit.

(9) dual operational modes (use with or without removable decontamination shield);
(10) removable external power pack for low-temperature display operations to $-40\,^{\circ}C$.

In addition, the probe has a twist-on swipe tray for use in the scalar mode for survey operations.

3. Detector housing

The electronic subassemblies are located inside an aluminum housing with an attached handle as shown in fig. 1. The entire radiac weighs approximately 0.9 kg (2 lb). The aluminum handle is designed so that the center of gravity is positioned over the center of the radiac, and can hold two "D" cell batteries that support operations with the stand-alone display unit.

The housing is constructed as a Faraday cage to protect the electronics from electromagnetic interference (EMI). The sensitive preamplifier is further enclosed in another aluminum housing to isolate it from both external EMI and internally generated noise from the DIU and PPU. In addition, a silicon seal between the DET Kevar ring and the housing reduces the unit's susceptibility to moisture.

Covering the silicon detector is a 8.4 cm diameter disposable decontamination shield. The shield is an aluminized Mylar film attached to a honeycomb-patterned aluminum screen that covers only 7.4% of the Mylar film.

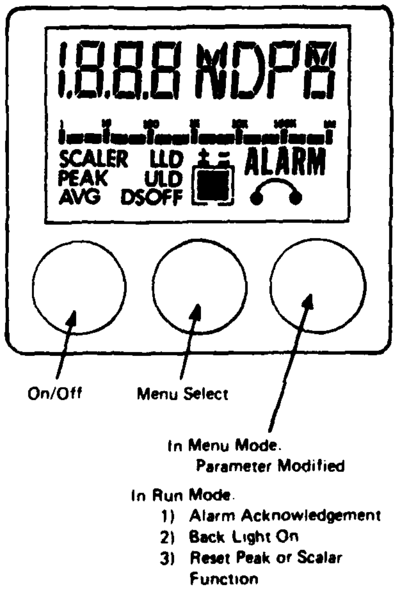

Fig. 2. Stand-alone display unit and function buttons.

Table 2
Stand-alone operational classes

Class 1: functions for field use
- Turn headphone audio on and off
- Adjust headphone volume
- Select either average of peak detection sampling
Class 2: Class 1 functions plus:
- Select display units (CPM, CPS, DPM, DPS)
- Operate the probe with or without decontamination shield
- Use scalar functions
Class 3: Class 2 functions plus:
- Adjust dual discrimination levels

4. Stand-alone display unit

The alpha radiac is designed to operate with either a multifunction radiac power/readout box, or the newly designed, detachable stand-alone display unit shown in fig. 2. This unit supports the functions listed in table 2. When the stand-alone display unit is used, two "D" batteries located in the radiac's handle supply power for both the radiac detector and display. The same cable used to connect the detector unit to the multifunction radiac power/readout box or calibrating computer is used with the stand-alone, back-lighted display unit. This stand-alone display unit can be programmed into one of three classes of operations listed in table 2. This permits the radiac to be used by personnel of differing qualifications and duties.

Table 3
Operational tests and results

Humidity	95% at 22.3°C for 4 h
Operating temperature range	−40° to +50°C
Storage temperature range	−65° to +71°C
Thermal shock	+23° to +50°C in 5 min +23° to −10°C in 5 min
Pressure/altitude operation	795–525 mm Hg (operational after exposure to 14.6 mm Hg)
Waterproof/splash proof	passed
Mechanical vibration	sinusoidal 5–500 Hz 10–33 Hz at 2*G* acceleration 11–2000 Hz randomly
Mechanical shock	18 ms shocks at 50*G* acceleration
Drop limits	1 m to hardwood floor/concrete
EMI tests	
Electric-field susceptibility:	14 kHz to 10 GHz
Magnetic-field susceptibility:	30 Hz to 50 kHz
Broadband EM emissions:	0.01 MHz to 1 GHz
Narrowband EM emissions:	0.01 MHz to 10 GHz

Table 4
Radiation response capabilities

Detector surface uniformity	4 mm increments <10% variation
Response time	1.5 s
Interfering radiation	gamma-ray, beta, neutron recorded response within 1 standard deviation
Resolution	300 keV FWHM
Count-rate reduction with decontamination shield	25% (point source)
Counting accuracy:	
point source	within 10% for sources > 460 dpm
large-area source	9.1% for 4800 dpm
Scanning rate	~ 63% confidence of detecting 200 dpm point source at 10 cm/s

5. Testing and evaluation

To ensure that the final product met the requirements of the users, testing of prototype alpha radiacs was performed at several military facilities and contracted civilian laboratories using both standard military test for equipment reliability and tests for evaluating radiation detection devices [5,6]. Tables 3 and 4 provide a listing of the tests and ranges of measurements performed [7].

6. Conclusion

The development of new radiation detection devices required (1) a review of current technologies, and (2) a cooperative effort between the developer and user. In developing a new alpha radiac for the U.S. military, user-demanded requirements allowed for the incorporation of many features that enhanced the original design. This approach led to the design of a radiac that meets the needs of a diverse number of operators with different requirements.

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